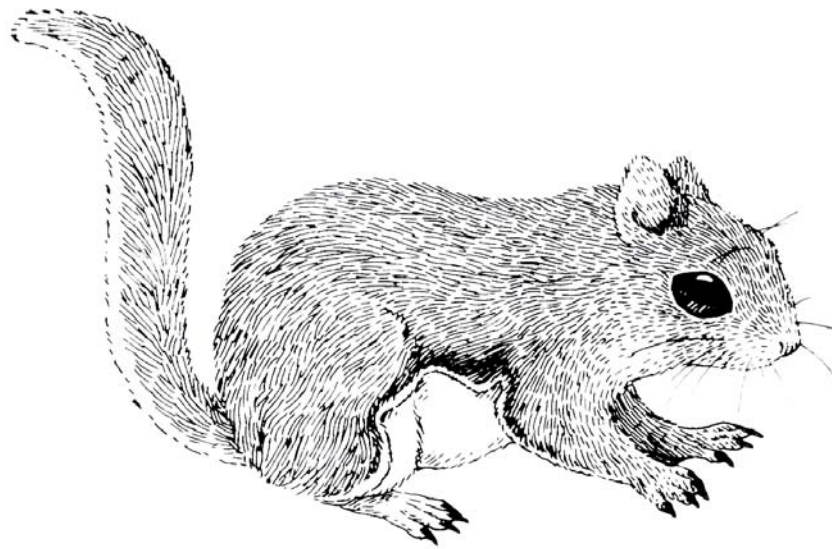**California Wildlife Habitat Relationships Program**
California Department of Fish and Game

HABITAT SUITABILITY MODELS FOR USE WITH ARC/INFO:
NORTHERN FLYING SQUIRREL

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HABITAT SUITABILITY MODELS FOR USE WITH ARC/INFO:
NORTHERN FLYING SQUIRREL

by

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NORTHERN FLYING SQUIRREL (*Glaucomys sabrinus*)

HABITAT USE INFORMATION

General

The northern flying squirrel (*Glaucomys sabrinus*) inhabits coniferous, mixed coniferous, and deciduous forests at altitudes from sea level to 2,000 m (6,600 ft) (Woods 1981). The species' range extends from the Arctic tree line across the northern forests of Canada and Alaska south through the Cascade Range of Oregon and Washington (Hall 1981). In California, they are locally common, yearlong residents of coniferous habitats from ponderosa pine (*Pinus ponderosa*) through lodgepole pine (*P. contorta* var. *murrayana*) forests (1,500 to 2,450 m [5,000 to 8,000 ft]) and of riparian-deciduous forests of the Warner Mountains and the Klamath, Cascade, and Sierra Nevada ranges (Zeiner et al. 1990). Northern flying squirrels are strictly nocturnal spending most of their time in trees, and they locomote by gliding up to 46 m (150 ft) (Weigl and Osgood 1974). They do not hibernate and are active throughout the year.

Food

Though northern flying squirrels subsist largely on fungi and lichens, they also consume mast, fruits, and animal matter such as insects, carrion and bird eggs (Ingles 1965; Weigl 1978; Woods 1981). A study of food habits in California revealed winter and summer diets dominated, respectively, by arboreal lichens, particularly hair moss (*Alectoria fremontii*), and various hypogeous and epigeous fungi (McKeever 1960). In the central Sierra Nevada, northern flying squirrels consumed 22 genera of fungi including 13 hypogeous fungi, 2 puffballs, 3 lichens, and 3 gill fungi (Hall 1991). Eight of the genera were consumed at different rates in different seasons, with 4 hypogeous fungi genera taken predominately during snow-free periods, and the remainder (three lichens and one gill fungus) eaten primarily during periods of snow cover (Hall 1991). In Oregon, 90% or more of the materials ingested by flying squirrels were fungi or lichens including 20 genera of hypogeous fungi (Maser et al. 1985). From December through June, hair moss lichen was the predominant food. During the balance of the year, hypogeous fungi were the principal food resources (Maser et al. 1985).

Water

No specific requirements have been reported in the literature. However, nests are frequently located near streams or rivers, and it is likely that drinking water is required during the summer (Zeiner et al. 1990).

Cover

Northern flying squirrels require a forest mosaic that includes adequate denning and feeding areas. Flying squirrels, although primarily cavity nesters (Weigl 1978), frequently build outside nests or drays of shredded cambium, moss, and lichens supported by branches (Cowan 1936) or witches' brooms (Mowrey and Zasada 1984). In Alaska, 61% of nests were in witches' brooms, 9% were classed as drays, and 30% were in cavities (Mowrey and Zasada 1984). Nest heights varied from an average of 8 m (26 ft) to 14 m (46 ft) in paper birch (*Betula papyrifera*) and white spruce (*Picea glauca*), respectively, while mean dbh of nest trees ranged from 22 cm (9 in) for paper birch to 33 cm (13 in) for white spruce (Mowrey and Zasada 1984).

In the Pacific Northwest, flying squirrels occur in pine (*Pinus* spp.), fir (*Abies* spp.), mixed conifer, Douglas-fir (*Pseudotsuga menziesii*), hemlock (*Tsuga* spp.), and spruce (*Picea* spp.) forests (Gunther and Kucera 1978), and they may be more abundant in old-growth stands than in second-growth stands (Harris and Maser 1984; Franklin 1988; Witt 1992). Tree cavities are more numerous in old forests where wood rot, frost cracking, woodpeckers, and carpenter ants have created or enlarged holes. The availability of cavities may be a significant factor affecting winter survival in areas where heavy precipitation and cold temperatures render more exposed nests uninhabitable (Cowan 1936; Maser 1981; Maser et al. 1981; Woods 1981). Old-growth stands, due to a more favorable micro-climate conducive to the growth of lichens and hypogeous fungi, may have more of these food sources than do second-growth stands. However, in the Cascade Range of Oregon, flying squirrel densities averaged 2.0 and 2.3 squirrels/ha (2.5 ac) in second and old-growth stands, respectively (Rosenberg and Anthony 1992). In California, flying squirrels were found in nearly equal proportions in small, medium, and large sawtimber seral stages of a Douglas-fir forest (Raphael et al. 1986). Similar numbers of flying squirrels were captured in Californian riparian and upland coniferous forests despite large differences in vegetation structure and composition between these habitats (Doyle 1990).

Reproduction

Northern flying squirrels generally breed once per year with litters born from May to July (Grinnell and Storer 1924; Cowan 1936; Ingles 1965; Maser et al. 1981). However, one incidence of fall breeding has been reported from Humboldt County (Raphael 1984), and 2 litters per year may be raised in the southern portion of the range (MacClintock 1970). The reproductive requirements of the northern flying squirrel are assumed to be met in the cover types described above.

Interspersion and Composition

Northern flying squirrels may form aggregations during the winter months and several individuals may be found sharing a nest (Mowrey and Zasada 1984). Aggregations within winter nests may help to reduce winter energy costs (Weigl 1978). During the breeding season, females occupy

nests with their young, but males may continue to share nests throughout the year (Maser et al. 1981). In the Sierra Nevada, the home range of a mother-young group was 2 ha (5 ac) (MacClintock 1970), while in the Oregon Coast Range home ranges varied from 3-5 ha (8-13 ac) (Witt 1992). The home range of northern flying squirrels in North Carolina and Pennsylvania varied from 5-13 ha (12-33 ac) and averaged 7 ha (18 ac) (Weigl and Osgood 1974).

In the Oregon Coast Range, mean density estimates were 0.12 squirrels/ha and 0.85 squirrels/ha (2.5 ac) in second and old-growth forests, respectively (Witt 1992). In the Cascade Range of Oregon, mean densities ranged from 2-2.3 squirrel/ha (2.5 ac) in second and old-growth stands (Rosenberg and Anthony 1992). Density differences between habitat types have also been noted in Utah (Andersen et al. 1980). These authors found varying densities along a montane-successional gradient. Whereas flying squirrels were absent from the montane meadow, the *Populus*-dominated forest had 0.2-1.8 squirrels/ha (2.5 ac); the *Abies*-dominated forest averaged 1.2 to 5.8 squirrels/ha (2.5 ac), and the *Picea*-dominated forest had 0.2-2.1 squirrels/ha (2.5 ac).

HABITAT SUITABILITY INDEX (HSI) MODEL

Model Applicability

Geographic area.

The California Wildlife Habitat-Relationships (CWHR) System (Airola 1988; Mayer and Laudenslayer 1988; Zeiner et al. 1990) contains habitat ratings for each habitat type predicted to be occupied by northern flying squirrel in California.

Season.

This model is designed to predict the suitability of habitat predicted to be occupied by northern flying squirrels throughout the year. Model predictions, however, may be more accurate for breeding habitat.

Cover types.

This model can be used anywhere in California for which an ARC/INFO map of CWHR habitat types exists. The CWHR System contains suitability ratings for reproduction, cover, and feeding for all habitats northern flying squirrels are predicted to occupy. These ratings can be used in conjunction with the ARC/INFO habitat map to model wildlife habitat suitability.

Minimum habitat area.

Minimum habitat area is defined as the minimum amount of contiguous habitat required before a species will occupy an area. Specific information on minimum areas required for northern flying

squirrels was not found in the literature. This model assumes two home ranges is the minimum area required to support a northern flying squirrel population during the breeding season.

Verification level.

The spatial model presented here has not been verified in the field. The CWHR suitability values used are based on a combination of literature searches and expert opinion. We strongly encourage field testing of both the CWHR database and this spatial model.

Model Description

Overview.

This model uses CWHR habitat type as the main factor determining suitability of an area for this species.

A CWHR habitat type map must be constructed in ARC/INFO GRID format as a basis for the model. The GRID module of ARC/INFO was used because of its superior functionality for spatial modeling. Only crude spatial modeling is possible in the vector portion of the ARC/INFO program, and much of the modeling done here would have been impossible without the abilities of the GRID module. In addition to more sophisticated modeling, the GRID module's execution speed is very rapid, allowing a complex model to run in less than 30 minutes.

The following sections document the logic and assumptions used to interpret habitat suitability.

Cover component.

A CWHR habitat map must be constructed. The mapped data (coverage) must be in ARC/INFO GRID format. A grid is a GIS coverage composed of a matrix of information. When the grid coverage is created, the size of the grid cell should be determined based on the resolution of the habitat data and the home range size of the species with the smallest home range in the study. You must be able to map the home range of the smallest species with reasonable accuracy. However, if the cell size becomes too small, data processing time can increase considerably. We recommend a grid cell size of 30 m (98 ft). Each grid cell can be assigned attributes. The initial map must have an attribute identifying the CWHR habitat type of each grid cell. A CWHR suitability value is assigned to each grid cell in the coverage based on its habitat type. Each CWHR habitat is rated as high, medium, low or of no value for each of three life requisites: reproduction; feeding; and cover. The geometric mean value of the three suitability values was used to determine the base value of each cell for this analysis.

Distance to water.

No water requirement was found for this species.

Species' distribution.

The study area must be manually compared to the range maps in the CWHR Species Notes (Zeiner et al. 1990) to ensure that it is within the species' range. All grid cells outside the species' range have a suitability of zero.

Spatial analysis.

Ideally, a spatial model of distribution should operate on coverages containing habitat element information of primary importance to a species. For example, in the case of woodpeckers, the size and density of snags as well as the vegetation type would be of great importance. For many small rodents, the amount and size of dead and down woody material would be important. Unfortunately, the large cost involved in collecting microhabitat (habitat element) information and keeping it current makes it likely that geographic information system (GIS) coverages showing such information will be unavailable for extensive areas into the foreseeable future.

The model described here makes use of readily available information such as CWHR habitat type, elevation, slope, aspect, roads, rivers, streams and lakes. The goal of the model is to eliminate areas that are unlikely to be utilized by the species and lessen the value of marginally suitable areas. It does not attempt to address all the microhabitat issues discussed above, nor does it account for other environmental factors such as toxins, competitors, or predators. If and when such information becomes available, this model could be modified to make use of it.

In conclusion, field surveys will likely discover that the species is not as widespread or abundant as predictions by this model suggest. The model predicts potentially available habitat. There are a variety of reasons why the habitat may not be utilized.

Definitions.

Home Range: the area regularly used for all life activities by an individual during the season(s) for which this model is applicable.

Dispersal Distance: the distance an individual will disperse to establish a new home range. In this model, it is used to determine if Potential Colony Habitat will be utilized.

Day to Day Distance: the distance an individual is willing to travel on a daily or semi-daily basis to utilize a distant resource (Potential Day to Day Habitat). The distance used in the model is the home range radius. This is determined by calculating the radius of a circle with an area of one home range.

Core Habitat: a contiguous area of habitat of medium or high quality that has an area greater than two home ranges in size. This habitat is in continuous use by the species. The species is successful enough in this habitat to produce offspring that may disperse from this area to the Colony Habitat and Other Habitat.

Potential Colony Habitat: a contiguous area of habitat of medium or high quality that has an area between one and two home ranges in size. It is not necessarily used continuously by the species. The distance from a core area will affect how often Potential Colony Habitat is utilized.

Colony Habitat: Potential Colony Habitat that is within the dispersal distance of the species. These areas receive their full original value unless they are further than three home range radii from a core area. These distant areas receive a value of low since there is a low probability that they will be utilized regularly.

Potential Day to Day Habitat: an area of high or medium quality habitat less than one home range, or habitat of low quality of any size. This piece of habitat alone is too small or of inadequate quality to be Core Habitat.

Day to Day Habitat: Potential Day to Day Habitat that is close enough to Core or Colony Habitat can be utilized by individuals moving out from those areas on a day to day basis. The grid cell must be within Day to Day Distance of Core or Colony Habitat.

Other Habitat: contiguous areas of low value habitat larger than two home ranges in size, including small areas of high and medium quality habitat that may be imbedded in them, are included as usable habitat by the species. Such areas may act as "sinks" because long-term reproduction may not match mortality.

The table below indicates the specific distances and areas assumed by this model.

Distance variables:	Meters	Feet
Dispersal Distance	4,500	14,765
Day to Day Distance/ Home Range radius	114	372

Area variables:	Hectares	M^2	Acres	Ft^2
Home Range	4.05	40,470	10	435,600
Core Habitat	8.09	80,940	20	871,200

Application of the Model

A copy of the ARC/INFO AML can be found in Appendix 1. The steps carried out by the macro are as follows:

1. **Determine Core Habitat**: this is done by first converting all medium quality habitat to high quality habitat and removing all low value habitat.   Then contiguous areas of habitat are grouped into regions. The area of each   of the regions is determined. Those large enough (two home ranges) are   maintained in the Core Habitat coverage. If no Core Habitat is identified then   the model will indicate no suitable habitat in the study area.

2. **Identify Potential Colony Habitat**: using the coverage from Step 1, determine which regions are one to two home ranges in size. These are Potential Colonies.

3. **Identify Potential Day Use Habitat**: using the coverage derived in Step 1, determine which areas qualify as Potential Day to Day Habitat.

4. **Calculate the Cost Grid**: since it is presumed to be more difficult for animals to travel through unsuitable habitat than suitable habitat we use a cost   grid to limit travel based on habitat suitability. The cost to travel is one for   high or medium quality habitat. This means that to travel 1 m through this   habitat costs 1 m of Dispersal Distance. The cost to travel through low   quality habitat is two and unsuitable habitat costs four. This means that to   travel 1 m through unsuitable habitat costs the species 4 m of Dispersal   Distance.

5. **Calculate the Cost Distance Grid**: a cost distance grid containing the minimum cost to travel from each grid cell to the closest Core Habitat is then calculated using the Cost Grid (Step 4) and the Core Habitat (Step 1).

6. **Identify Colony Habitat**: based on the Cost Distance Grid (Step 5), only Potential Colony Habitat within the Dispersal Distance of the species to   Core Habitat is retained. Colonies are close enough if **any** cell in the Colony   is within the Dispersal Distance from Core Habitat. The suitability of any   Colony located further than three home range radii from a Core Habitat is   changed to low since it is unlikely it will be utilized regularly.

7. **Create the Core + Colony Grid**: combine the Core Habitat (Step 1) and the Colony Habitat (Step 6) and calculate the cost to travel from any cell to Core   or Colony Habitat. This is used to determine which Potential Day to Day   Habitat could be utilized.

8.   **Identify Day to Day Habitat**: grid cells of Day to Day Habitat are only accessible to the species if they are within Day to Day Distance from the edge   of the nearest Core or Colony Habitat. Add these areas to the Core + Colony   Grid (Step 7).

9.   **Add Other Habitat**: large areas (two home ranges in size) of low value habitat, possibly with small areas of high and medium habitat imbedded in   them may be utilized, although marginally. Add these areas back into the   Core + Colony + Day to Day Grid (Step 8), if any exist, to create the grid   showing areas that will potentially be utilized by the species. Each grid cell   contains a one if it is utilized and a zero if it is not.

10.   **Restore Values**: All areas that have been retained as having positive habitat value receive their original geometric mean value from the original geometric   value grid (see *Cover component* section) with the exception of distant   colonies. Distant colonies (colonies more than three home range radii distant)   have their value reduced to low because of the low likelihood of utilization.

Problems with the Approach

Cost.

The cost to travel across low suitability and unsuitable habitat is not known. It is likely that it is quite different for different species. This model incorporates a reasonable guess for the cost of movement. A small bird will cross unsuitable habitat much more easily than a small mammal. To some extent, differences in vagility between species is accounted for by different estimates of dispersal distances.

Dispersal distance.

The distance animals are willing to disperse from their nest or den site is not well understood. We have used distances from studies of the species or similar species when possible, otherwise first approximations are used. More research is urgently needed on wildlife dispersal.

Day to day distance.

The distance animals are willing to travel on a day to day basis to use distant resources has not been quantified for most species. This issue is less of a concern than dispersal distance since the possible distances are much more limited, especially with small mammals, reptiles, and amphibians. Home range size is assumed to be correlated with this coefficient.

SOURCES OF OTHER MODELS

No other habitat models were found for the northern flying squirrel.

REFERENCES

Airola, D.A. 1988. Guide to the California Wildlife Habitat Relationship System. Calif. Dept. of Fish and Game, Sacramento, California. 74 pp.

Andersen, D.C., J.A. MacMahon, and M.L. Wolfe. 1980. Herbivorous mammals along a montane sere: community structure and energetics. J. Mammal. 61(3):500-519.

Cowan, I. McT. 1936. Nesting habits of the flying squirrel, *Glaucomys sabrinus*. J. Mammal. 49(3):531-537.

Doyle, A.T. 1990. Use of riparian and upland habitats by small mammals. J. Mammal. 71(1):14-23.

Franklin, J.F. 1988. Structural and functional diversity in temperate forests. Pages 166-175 *in* E.O. Wilson, ed. Biodiversity. National Academy Press, Washington, D.C.

Grinnell, J., and T.I. Storer. 1924. Animal life in the Yosemite. Univ. of Calif. Press, Berkeley, California. 752 pp.

Gunther, K., and J.E. Kucera. 1978. Wildlife of the Pacific Northwest: occurrence and distribution by habitat, BLM District, and National Forest. U.S.D.A., For. Serv., Pac. NW Reg. 128 pp.

Hall, D.S. 1991. Diet of the northern flying squirrel at Sagehen Creek, California. J. Mammal. 72(3):615-617.

Hall, E.R. 1981. The Mammals of North America. 2nd ed. 2 vols. John Wiley and Sons, New York. 1271 pp.

Harris. L.D., and C. Maser. 1984. Animal community characteristics. Pages 44-68 *in* L.D. Harris, ed. The fragmented forest. Univ. of Chicago Press, Chicago, Illinois.

Ingles, L. 1965. Mammals of the Pacific States. Stanford Univ. Press, Stanford, California. 506 pp.

MacClintock, D. 1970. Squirrels of North America. Van Nostrand Reinhold, Co., New York. 184 pp.

Maser, C. 1981. Land mammals. Pages 35-371 *in* C. Maser, B.R. Mate, J. F. Franklin, and C. T. Dyrness, eds. Natural history of Oregon coast mammals. U.S.D.A., For. Serv., Pac. NW For. and Range Expt. Stat., Gen. Tech. Rep. No. PNW-133.

Maser, C., R. Anderson, and E.L. Bull. 1981. Aggregation and sex segregation in northern flying squirrels in northeastern Oregon, an observation. Murrelet 62:54-55.

Maser, Z., C. Maser, and J.M. Trappe. 1985. Food habits of the northern flying Squirrel *Glaucomys sabrinus* in Oregon. Can. J. Zool. 63:1084-1088.

Mayer, K.E., and W.F. Laudenslayer, Jr. eds. 1988. A guide to wildlife habitats of California. Calif. Dept. of Fish and Game, Sacramento, California. 166 pp.

McKeever, S. 1960. Food of the northern flying squirrel in northeastern California. J. Mammal. 41(2):270-271.

Mowrey, R.A., and J.C. Zasada. 1984. Den tree use and movements of northern flying squirrels in interior Alaska and implications for forest management. Pages 351-356 *in* W.R. Mechan, T.R. Merrell, Jr., and T.A. Hanley, eds. Fish and wildlife relationships in old-growth forests. Am. Inst. Fish. Res. Biol., Moorhead City, North Carolina.

Raphael, M.G. 1984. Late fall breeding of the northern flying squirrel, *Glaucomys sabrinus*. J. Mammal. 65(1):138-139.

Raphael, M.G., C.A. Taylor, and R.H. Barrett. 1986. Smoked aluminum track stations record flying squirrel occurrence. U.S.D.A., For. Serv., Pac. SW For. and Range Expt. Stat., Res. Note PSW-384. 3 pp.

Rosenberg, D.K., and R.G. Anthony. 1992. Characteristics of northern flying squirrel populations in young second-and old-growth forests in western Oregon. Can. J. Zool. 70:161-166.

Weigl, P.D. 1978. Resource overlap, interspecific interactions and the distribution of the flying squirrels, *Glaucomys volans* and *G. sabrinus*. Am. Midl. Nat. 100(1): 83-96.

Weigl, P.D., and D.W. Osgood 1974. Study of the northern flying squirrel, *Glaucomys sabrinus*, by temperature telemetry. Am. Midl. Nat. 92(2):482-486.

Witt, J.W. 1992. Home range and density estimates for the northern flying squirrel, *Glaucomys sabrinus*, in western Oregon. J. Mammal. 73(4):921-929.

Woods, S.E., Jr. 1981. The Squirrels of Canada. Nat. Mus. of Canada, Ottawa, Canada. 199 pp.

Zeiner, D.C., W.F. Laudenslayer, Jr., K.E. Mayer, and M. White, eds. 1990. California's Wildlife. Vol. 3. Mammals. Calif. Dept. Fish and Game, Sacramento, California. 407 pp.
APPENDIX 1: Northern Flying Squirrel Macro

```
/*          NORTHERN FLYING SQUIRREL

/* nfsmodel.aml - This macro creates an HSI coverage for the
/*                Northern Flying Squirrel.

/* Version:  Arc/Info 6.1 (Unix), GRID-based model.

/* Authors:  Irene Timossi, Sarah Miller, Wilde Legard,
/*           and Reginald H. Barrett
/*           Department of Forestry & Resource Management
/*           University of California, Berkeley

/* Revision: 2/10/95

/* ------------------------------------------------------------------

/* convert .ID to uppercase for info manipulations

&setvar .ID [translate %.ID%]

/* Start Grid

grid

/*

&type (1)  Initializing Constants...

/*   Homerange: the size of the species' homerange.

/*   DayPay: The amount the species is willing to pay traveling on
/*   a day-to-day basis.  Used to determine the area utilized on a
/*   day-to-day basis.

/*   DispersePay: Distance traveled when dispersing.  The amount
/*   the animal is willing to pay when dispersing from a core area.

/*   High:  The value in the WHR grid which indicates high quality habitat.

/*   Medium:  The value in the WHR grid which indicates medium quality habitat.

/*   Low:  The value in the WHR grid which indicates low quality habitat.

/*   None:  The value in the WHR grid which indicates habitat of no value.

/*   SpecCode: The WHR code for the species

/*   AcreCalc:  The number needed to convert square units
/*              (feet or meters) to acres.


&setvar SpecCode = M080

&if %.Measure% = Meters &then
  &do
    &setvar Homerange      = 40470
    &setvar DayPay         = 114
```

```
      &setvar DispersePay    = 4500
      &setvar AcreCalc       = 4047
    &end
&else
  &if %.Measure% = Feet  &then
    &do
      &setvar Homerange     = 435600
      &setvar DayPay        = 372
      &setvar DispersePay   = 14765
      &setvar AcreCalc      = 43560
    &end
   &else
     &do
       &type Measurement type incorrect, check spelling.
       &type Only Meters and Feet are correct.
       &goto &BADEND
     &end


&setvar High        = 3
&setvar Medium      = 2
&setvar Low         = 1
&setvar None        = 0


/*   The following global variables are declared in the menu:

/*   .WHRgrid (WHR grid name): the name of the grid containing all
/*   the WHR information.

/*   .Bound (Boundary grid name): the grid containing only the
/*   boundary of the coverage. All cells inside the boundary
/*   have a value of 1. All cells outside the boundary must
/*   have a value < 1.

/*   .ID (Identifier): a 1 to 4 character code used to identify
/*   the files produced by this program. You may prefer
/*   to use an abbreviation of the species' common name
/*   (e.g. use `fis1` for fisher).

/*   .SizeOfCell (Cell size): the size (width) of the cells
/*   used in the coverage grids. All grids used in the
/*   analysis must have the same cell size.

/*   .Measure:  the units the coverage is measured in (feet or meters).


&type (2)  Creating working grid of geometric means...

/*   Create a Geometric Means grid (Geom) for the species by
/*   copying these values from the WHR grid.

Geom = %.WHRgrid%.%SpecCode%_G

/*

&type (3)  Changing %Medium% value cells to %High% value for Merge grid...

/*   Create a grid (Merge) merging Medium and High
/*   value cells from the Geometric mean grid (Geom),
```

/*   while leaving the value of other cells (Low and None) unchanged.
/*   Merge by changing the value of all medium cells to High.

Merge = con(Geom == %Medium%,%High%,Geom)

/*

&type (4) Converting Merge grid zones into a Region grid...

/*   Convert the zones of the merge grid (Merge) into
/*   unique regions (Region). These will be used later
/*   to create core, colony, and day-to-day areas.

Region = regiongroup(Merge,#,EIGHT)

/*

&type (5) Calculating the area of Region grid zones...

/*   Calculate the area of the zones (ZoneArea) on the region
/*   grid (Region).

ZoneArea = zonalarea(Region)

/*

&type (6) Creating a Core Area grid...

/*   Extract areas from the zonal area grid (ZoneArea)
/*   suitable for core areas (Core). Core areas are defined
/*   as the Medium+High zones in the merge grid (Merge)
/*   with an area of at least two home ranges (%Homerange%).
/*   Set their value = 1.

if (Merge == %High% and ZoneArea >= %Homerange% * 2)
  Core = 1
endif

&if not [exists Core -vat] &then
  &goto END

/*

&type (7) Creating a Colony grid...

/*   Extract areas from the zonal area grid (zoneArea)
/*   possibly suitable for colonization (ColTemp).
/*   Colony areas are defined as Low or Medium+High zones
/*   in the Merge grid (Merge) with an area of between one
/*   and two home ranges (%Homerange%). Set their value = 1.

/*   Then set all nodata values in the grid to zero (Colony).

docell
  if (Merge == %High%)
    if (ZoneArea > %Homerange% and ZoneArea < %Homerange% * 2)
     ColTemp = 1
    endif

15

```
  endif
end

Colony = con(isnull(ColTemp),0,ColTemp)

/*

&type (8)  Creating a Day-to-Day Use grid...

/*    Create a grid based on the values in the zonal
/*    area grid (ZoneArea) and merge grid (Merge)
/*    suitable for day-to-day use (DayToDay). Day-to-day use
/*    areas are defined as Low if the area is less than two
/*    homeranges in size or Medium+High zones in the
/*    merge grid (Merge) with an area of less than one home
/*    range (%Homerange%). Set their value = 1.

if ((Merge > %Low% and ZoneArea <= %Homerange%) or ~
   (Merge == %Low% and ZoneArea < %Homerange% * 2))
  DayToDay = 1
else
  DayToDay = 0
endif

/*

&type (9)  Creating a Cost Grid based on habitat value...

/*    Using the merge grid (Merge), create a cost grid (Cost)
/*    based on the habitat-value. Cost represents the relative
/*    resistance a species has to moving across different quality
/*    habitat:   Habitat-value   Cost
/*               None            4
/*               Low             2
/*               Medium+High     1

if (Merge == %None%)
   Cost = 4
else if (Merge == %Low%)
   Cost = 2
else if (merge == %High%)
  Cost = 1
endif

/*

&type (10) Calculating cost to travel from Core Areas...

/*    Calculate the cost to travel the distance (CostDist)
/*    from the nearest core area source (Core) using the cost
/*    grid (Cost).
/*

CostDist = CostDistance(Core,Cost)

/*

&type (11) Calculating which Colony areas are Cost Effective...
```

```
/*      If Colony Areas exist...
/*      Find the areas in the Colony grid (Colony) that could
/*      be colonized from the core areas:

/*      Assign costs to all cells in the Colony areas (Colony)
/*      from the Cost grid (CostDist). Zero surrounding NODATA areas.

/*      Make each colony a separate zone (ZoneReg) using
/*      the regiongroup command.

/*      Use zonalmin to find the minimum cost to arrive at each
/*      colony (ZoneMin).

/*      Set all NODATA cells to zero in ZoneMin to produce
/*      ColZer1.

/*      To find out which of the potential colonies can be utilized,
/*      determine which have a cost that is equal to or less than
/*      DispersePay. If the cost to get to a colony is less than
/*      or equal to DispersePay, keep it in grid Col.

/*      Fill the null value areas in Col with zeros to create ColZer2


&if not [exists ColTemp -vat] &then
  &goto SkipColony

ColDist = con(Colony > 0,CostDist,0)
ZoneReg = regiongroup(Colony,#,EIGHT)
ZoneMin = zonalmin(ZoneReg,ColDist)
ColZer1 = con(isnull(ZoneMin),0,ZoneMin)

if (ColZer1 <= %DispersePay% and ColZer1 > 0)
  Col = Colony
else
  Col = Core
endif

ColZer2 = con(isnull(Col),0,Col)

/*

&type (12)  Creating Core + Colony grid...

/*      If colonies exist....
/*      Create a grid (ColCore) that combines the core
/*      (Core) and colony (Colony) grids.
/*      This grid will be used to analyze day-to-day use.


if (Colony == 1)
  ColCore = 1
else
  ColCore = Core
endif

&label SkipColony
```

&type (13) Calculate cost to travel from Core and Colony Areas...

```
/*    If colonies exist...
/*    Calculate the cost to travel the distance (CostDis2)
/*    from the nearest core or colony area source (ColCore).
/*    Otherwise just copy the CostDist grid to use for Day-to-Day
/*    analysis.

&if not [exists ColTemp -vat] &then
  CostDis2 = CostDist
&else CostDis2 = CostDistance(ColCore,Cost)

/*
```

&type (14) Calculating which Day-to-Day areas are Cost Effective...

```
/*    This step adds the utilized Day-to-Day cells to the
/*    Core + Colony Area grid (ColZer2) to produce the
/*    Day1 grid.

/*    Use the Core + Colony Cost grid (CostDis2)to find out
/*    what can actually be used day-to-day (any cell with
/*    a cost of DayPay or less).

/*    Retain any cell in the Day-to-Day grid (DayToDay) with
/*    a cost less than or equal to DayPay and greater than zero.

/*    If the Distance-Cost grid (CostDis2) = 0,
/*    it is part of the Core or Colony Area and
/*    should gets its value from Core + Colony Area
/*    grid (ColZer2).

&if [exists ColTemp -vat] &then
  &do
   if (CostDis2 <= %DayPay% and CostDis2 > 0)
    Day1 = DayToDay
   else
    Day1 = ColZer2
   endif
  &end
&else
  &do
   if (CostDis2 <= %DayPay% and CostDis2 > 0)
    Day1 = DayToDay
   else
    Day1 = Core
   endif
  &end

/*
```

&type (15) Finding Other Areas That May Be Utilized....

```
/*    This step picks up any large low value areas and any small
/*    medium or high value polygons that are imbeded
/*     in them.

/*    First find any areas that are not currently in the included
```

```
/*      set (Day1Z) but are in the original geometric mean coverage (geom)
/*      set Other to 1 where Day1Z = 0.

/*      if Other is all nodata, create the All coverage from
/*      the Day1Z coverage.

/*      Split all other areas into separate regions (OthReg)

/*      Calculate the area of the regions (OthArea).

/*      Keep any region in OthArea with an area > 2 homeranges (Util).

/*      Change any null values in Util to zeros (OthZero).

/*      Add these areas to the Day1 coverage to create All

Day1Z = con(isnull(Day1),0,Day1)

if ((Day1Z < 1) and (Geom > 0))
  Other = 1
endif

&if not [exists Other -vat] &then
  All = Day1Z
&else
  &do
    OthReg = regiongroup(other,#,EIGHT)

    OthArea  = zonalarea(OthReg)

    if (OthArea >= %Homerange% * 2)
      Util = 1
    else
      Util = 0
    endif

    OthZero = con(isnull(Util),0,Util)

    if (OthZero == 1)
      All = OthZero
    else
      All = Day1Z
    endif
  &end

/*

&type (16) Creating a Value grid...

/*      For any cell in All that has a value of 1, store the suitability
/*      value from the Geometric mean grid (Geom) to the Value grid.

/*      Other cells inside the boundary (%.Bound%) get a value of 0.

/*

if (All == 1)
  Value = Geom
```

```
else if (%.Bound% == 1)
  Value = 0
endif

/*

&type (17)  Creating an HSI grid...

/*    if Colonies exist....
/*    For any cell that was part of a colony that is further than
/*    3 times the HR radius (DayPay) away from a core area, set the suitability
/*    to Low.  Distant colonies lose value because of their small size.
/*    This step produces grid Collow.

/*    Set all NODATA values in Collow to zero in ColZer3.

/*    Find any day-to-day use areas (DayToDay) that are being
/*    utilized (ColZer3).  If they are further than four homeranges
/*    from a core area (CostDist), they are utilized from a distant
/*    colony and their value will be decreased to Low in Day2.


/*    Then change nulls to zero in ValZero

/*    Keep all data within the boundary; call this final grid HSI.

&if [exists ColTemp -vat] &then
  &do
    if (ColZer1 >= %DayPay% * 3)
      Collow = %Low%
    else
      Collow = Value
    endif

    ColZer3 = con(isnull(Collow),0,Collow)

    if ((CostDist > %DayPay% * 4) and (ColZer3 > 0) and ~
       (DayToDay == 1))
      Day2 = 1
    else
      Day2 = ColZer3
    endif
  &end
&else
    Day2 = Value

valzero = con(isnull(Day2),0,Day2)

if (%.Bound% == 1)
  %.ID%hsi = valzero
endif

/*

&type (18)  Quiting from GRID and adding the acres field.....

/*    Quit from GRID (Q), then run additem to add an acre item to
/*    the HSI grid vat file (%ID%HSI.vat). Reindex on value when done.
```

20

```
Q
additem %.ID%hsi.vat %.ID%hsi.vat acres 10 10 i
indexitem %.ID%hsi.vat value

/*

&type (19)  Calculating acres.....

/*    Use INFO to calculate the acreage field: Multiply the number
/*    of cells by the cell size squared and divide by the number of
/*    square meters per acre (4047).  Reindex on value when done.

&data arc info
arc
select %.ID%hsi.VAT
CALC ACRES = ( COUNT * %.SizeOfCell% * %.SizeOfCell% ) / %AcreCalc%
Q STOP

&END

indexitem %.ID%hsi.vat value

/*

&type  (20) Killing all intermediate coverages before ending macro...

/* &goto OKEND

grid

kill Geom
kill Merge
kill Region
kill ZoneArea
kill Core
kill ColTemp
kill Colony
kill DayToDay
kill Cost
kill CostDist
kill ColDist
kill ZoneReg
kill ZoneMin
kill ColZer1
kill Col
kill ColZer2
kill ColCore
kill CostDis2
kill Day1
kill Day1Z
kill Other
kill OthReg
kill OthArea
kill Util
kill OthZero
kill All
kill Value
kill Collow
```

```
kill ColZer3
kill Day2
kill valzero

q

&goto OKEND

&label END
&type **
&type **
&type NO CORE AREAS EXIST, EXITING MACRO
&type **
&type **

kill Core
kill Region
kill ZoneArea
kill Merge
kill Geom

quit

&label OKEND
&label BADEND

&type -–----------- All done! ---–----------

&return
```